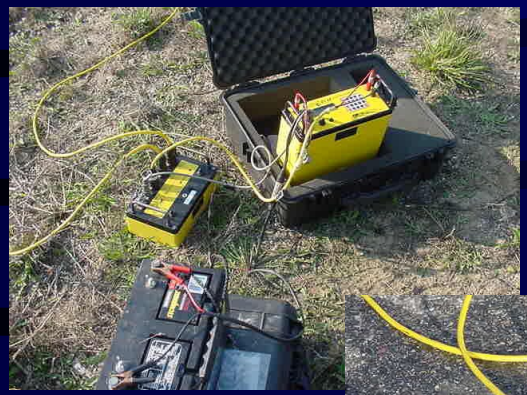
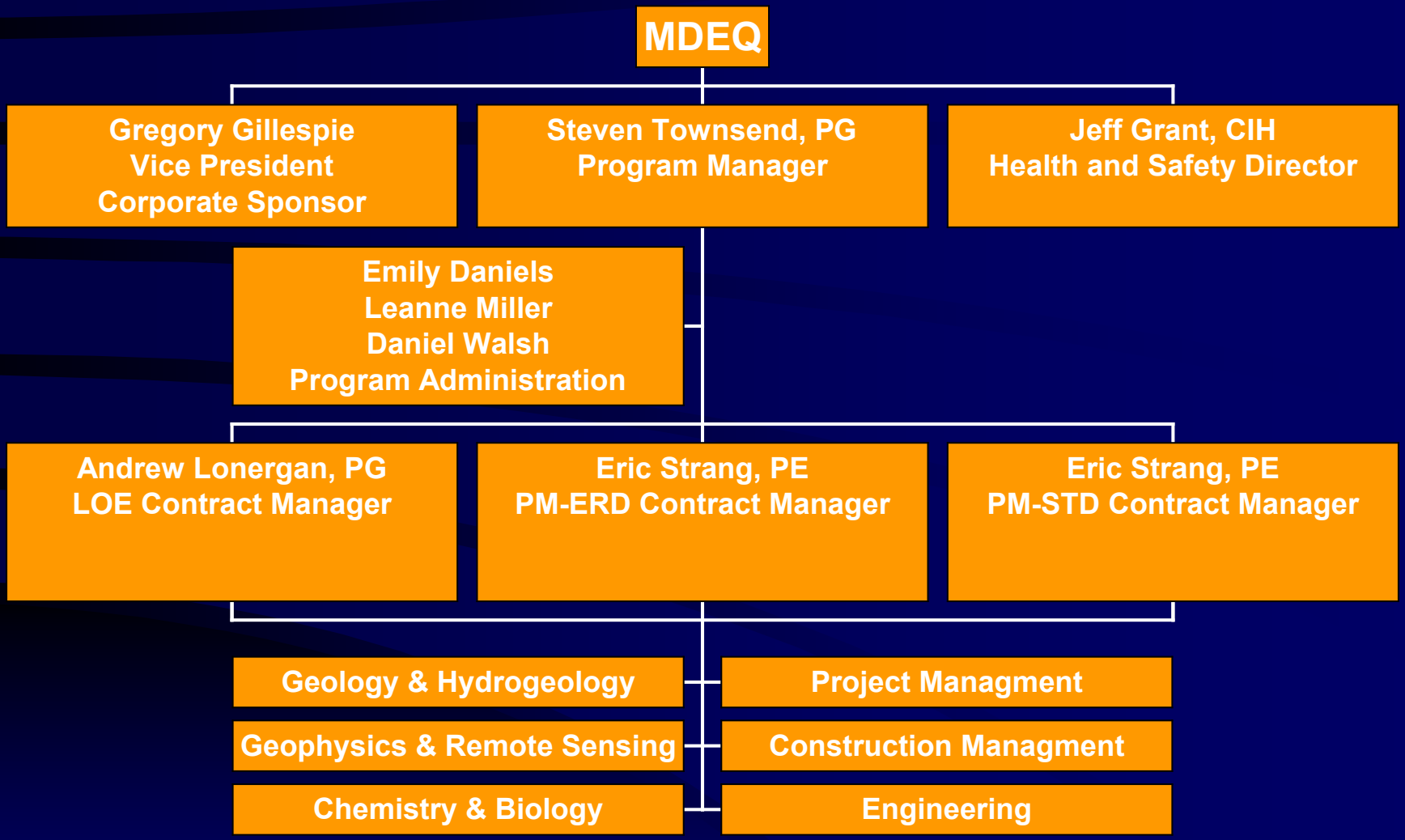


Surficial Geophysical Techniques for the Targeting of Dense Non-Aqueous Phase Liquids (DNAPLs)

Andrew Lonergan, Kristopher Nolan, Steven Townsend

Earth Tech, Inc.

March 2002


MDEQ
Gregory Gillespie
Vice President
Corporate Sponsor
Steven Townsend, PG
Program Manager
Jeff Grant, CIH
Health and Safety Director
Emily Daniels
Leanne Miller
Daniel Walsh
Program Administration
Andrew Lonergan, PG
LOE Contract Manager
Eric Strang, PE
PM-ERD Contract Manager
Eric Strang, PE
PM-STD Contract Manager
Geology & Hydrogeology
Geophysics & Remote Sensing
Chemistry & Biology
Project Managment
Construction Managment
Engineering

Problem Statement

Do You Suspect DNAPL?

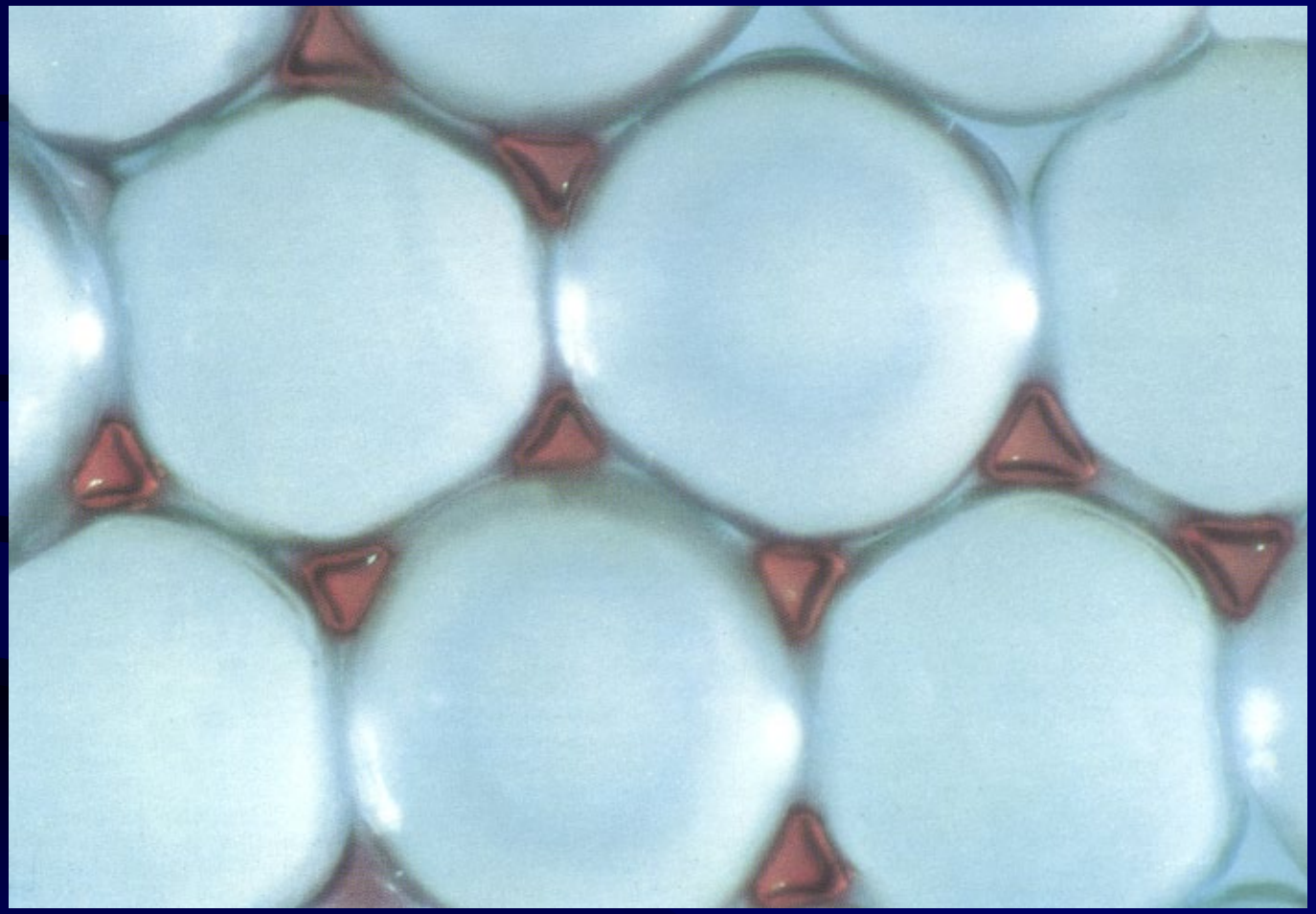
- Locating it
  - Many Borings
  - Many Wells
  - Did you actually find it?
- Remedy Selection
  - Shot in the dark…will it work?
  - Cross Fingers…$$

Fate and Transport of DNAPL

- Pore Pressure is Key

Unsaturated Zone

Saturated Zone



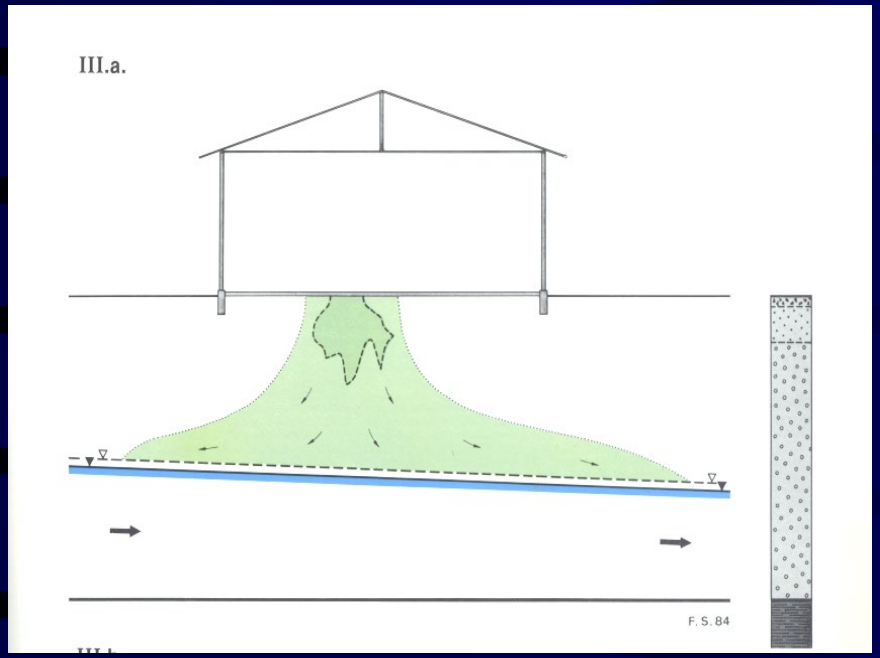
Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 89, Figure XV.a.

Fate and Transport of DNAPL

Pore Pressure is Key

Unsaturated Zone

Saturated Zone

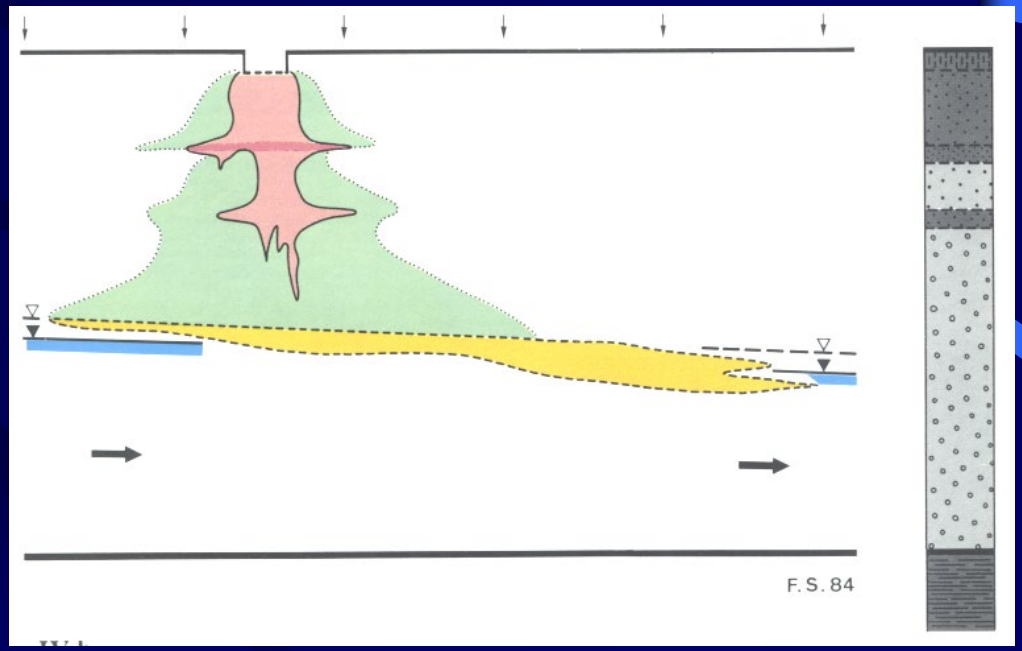


Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 77, Figure III.a.

Unsaturated Zone

Gas Phase is Dense

Lithologic Control (lentincular silts/clays)



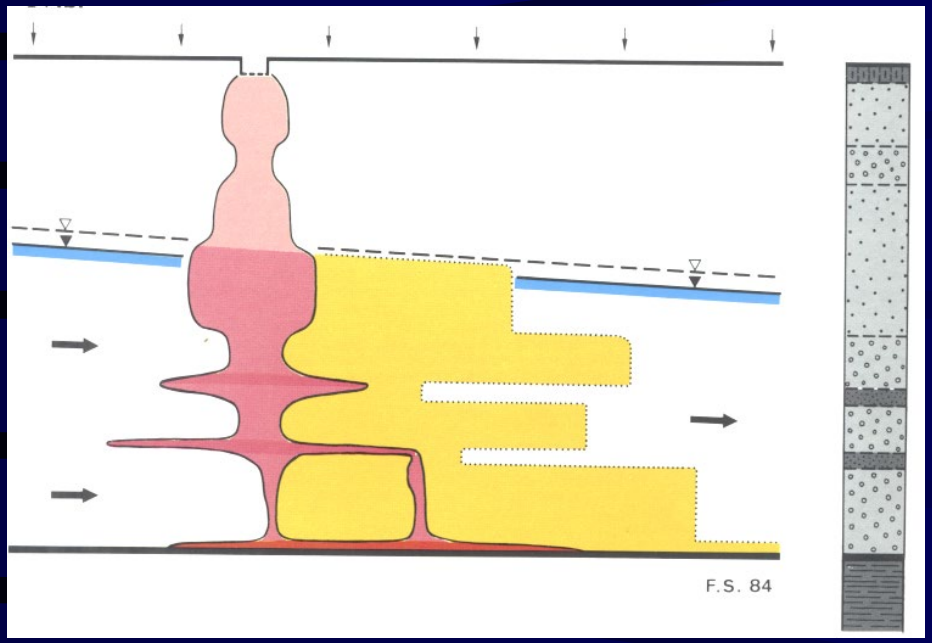
Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 77, Figure III.b.

Fate and Transport of DNAPL

Pore Pressure is Key

Unsaturated Zone

Saturated Zone

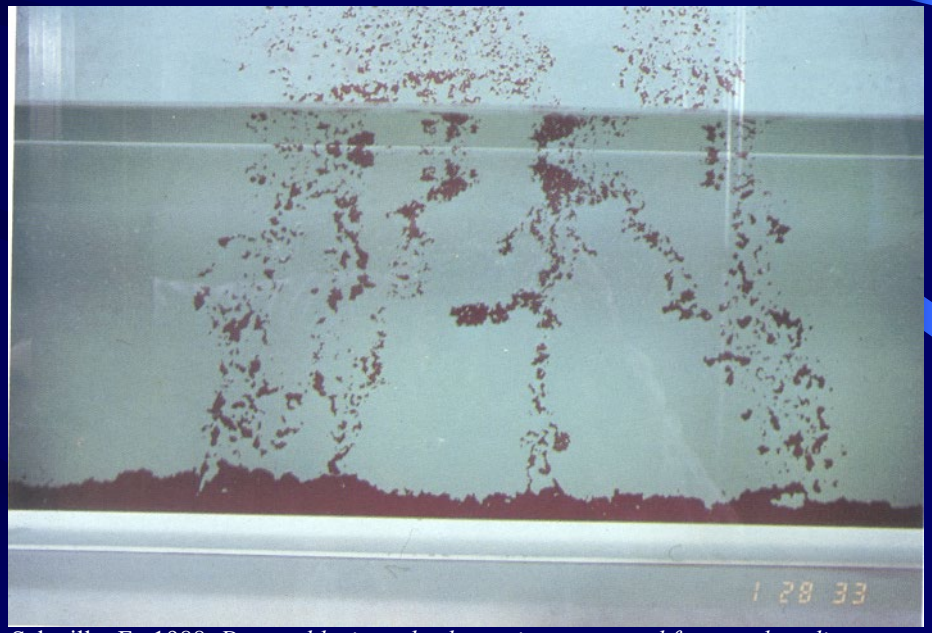


Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 78, Figure IV.b.

Saturated Zone

Lithologic Control
(lentincular silts/clays)

Globular Movement



Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 98, Figure XXIII.b.

Application of Geophysics to DNAPL

- Locate DNAPL without drilling
  - Does not poke holes in aquitards
  - Covers large areas at high resolution
- Focuses the investigation
  - 3D model of DNAPL and stratigraphy
- Improves remedy selection
  - Reduces Uncertainty
  - Increases Potential for Success

Proven Technology
New Application

- Induced Polarization
  - Mineral Exploration
- Seismic
  - Reflection
    - Oil and Gas, Mineral Exploration
  - Refraction
    - Geotechnical, Water Resources

Induced Polarization

Physics of DNAPL/LNAPL

Dielectric Constant

Membrane Polarization

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990. *Applied Geophysics* 2nd ed., Cambridge University Press

Capacitor Model

DNAPL seen in grains explains Chargeability

Equipment for Data Collection

Water = 80.4

DNAPLs

PCE = 2.2

TCE = 3.3

Carbon Tet. = 2.2

PCB ~ 2.0

LNAPLs

Toluene = 2.4

Benzene = 2.3

PAH/PNA ~ 2.2

Induced Polarization

Physics of DNAPLs

Dielectric Constant

Membrane Polarization

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990. *Applied Geophysics* 2nd ed., Cambridge University Press

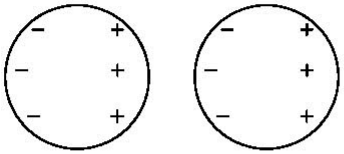
Capacitor Model

DNAPL seen in grains explains Chargeability

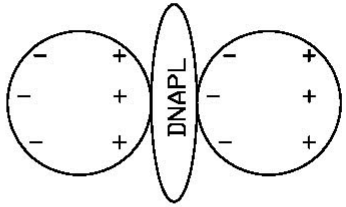
Equipment for Data Collection

SOIL GRAIN MODEL

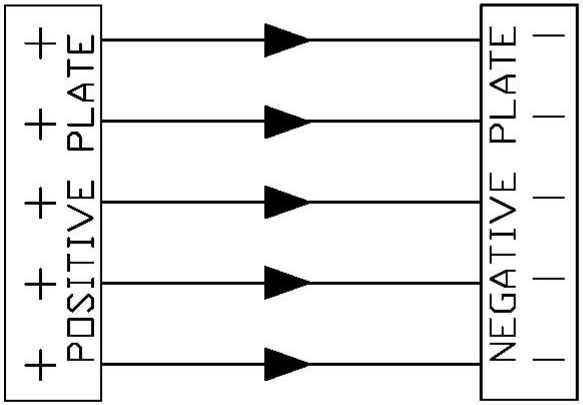
UNDER CURRENT
* NO DNAPL

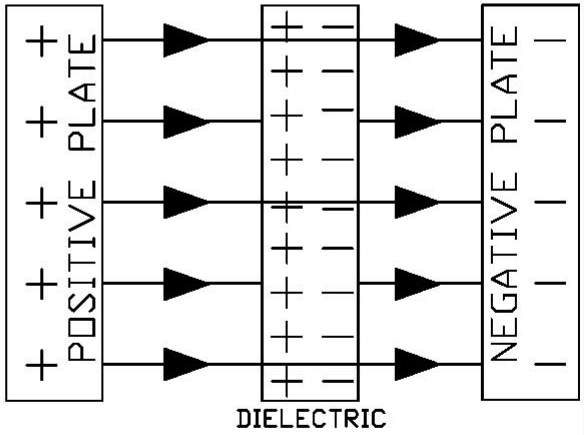


UNDER CURRENT
* WITH DNAPL



CAPACITOR MODEL





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Physics of DNAPLs

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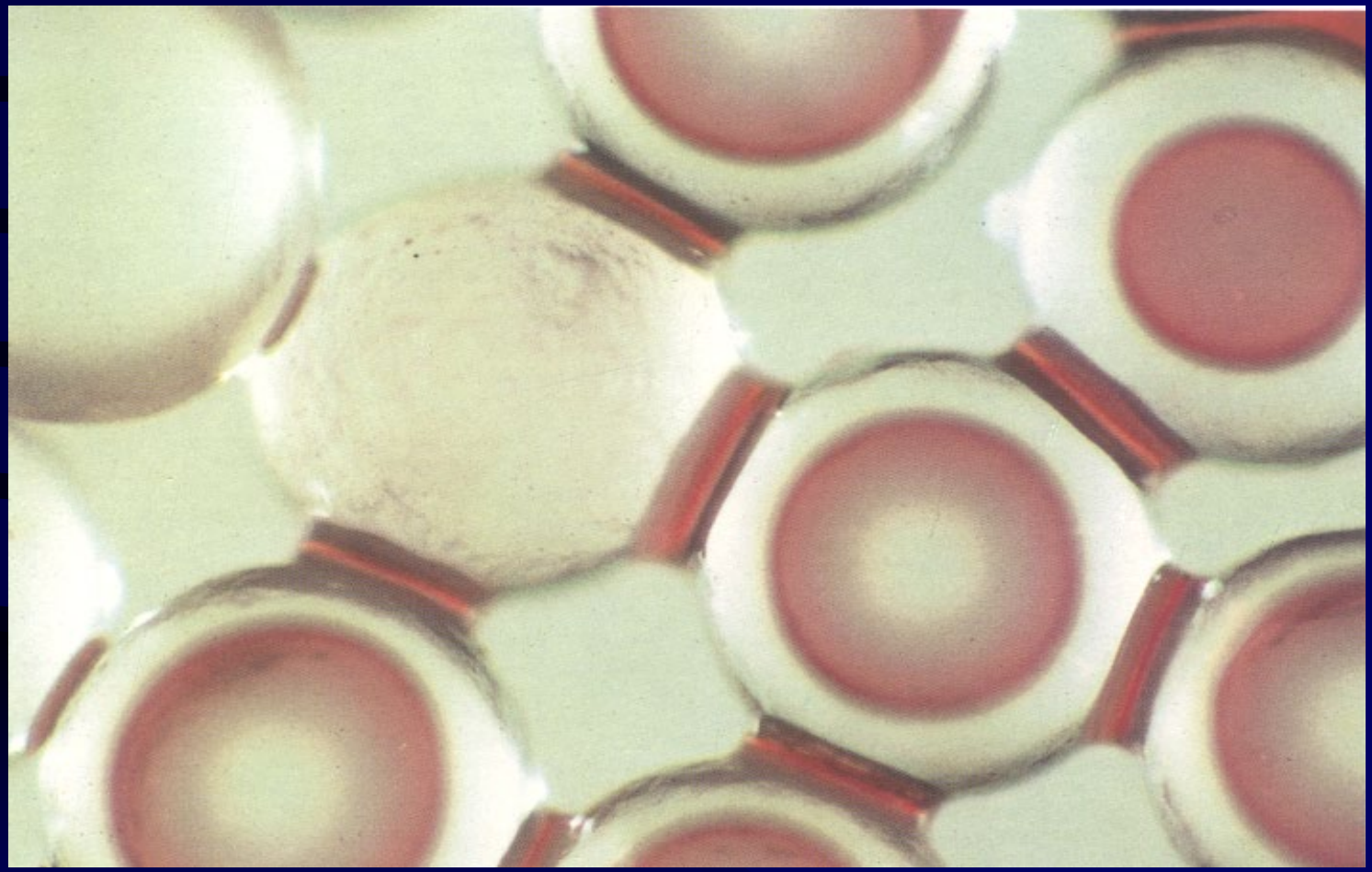
Capacitor Model

DNAPL seen in grains explains Chargeability

Equipment for Data Collection



Schwille, F., 1988. *Dense chlorinated solvents in porous and fractured media*. Translated by James F. Pankow. Lewis Publishers, Inc. p. 89, Figure XIV.a.

Induced Polarization

Physics of DNAPLs

Dielectric Constant

Membrane Polarization

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990. *Applied Geophysics* 2nd ed., Cambridge University Press

Capacitor Model

DNAPL seen in grains explains Chargeability

Equipment for Data Collection

- Sting R1/IP Transmitter/Receiver
- Swift Automatic Digital Switching System
- 56-Electrode Array Cables
- Stainless Steel Stakes
- Water Softener Salt (NaCl)
- Topographic Survey Equipment
- GPS Survey Equipment

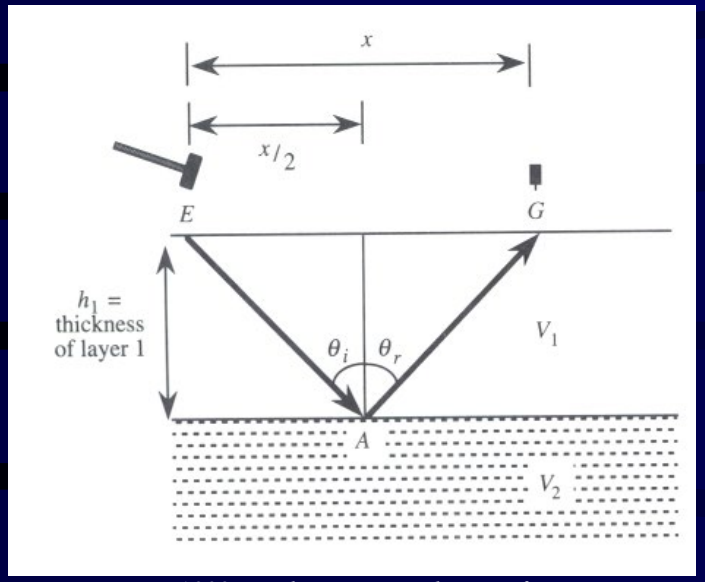
Seismic Mapping

Stratigraphic Mapping

- Reflection or Refraction of Induced Seismic Waves

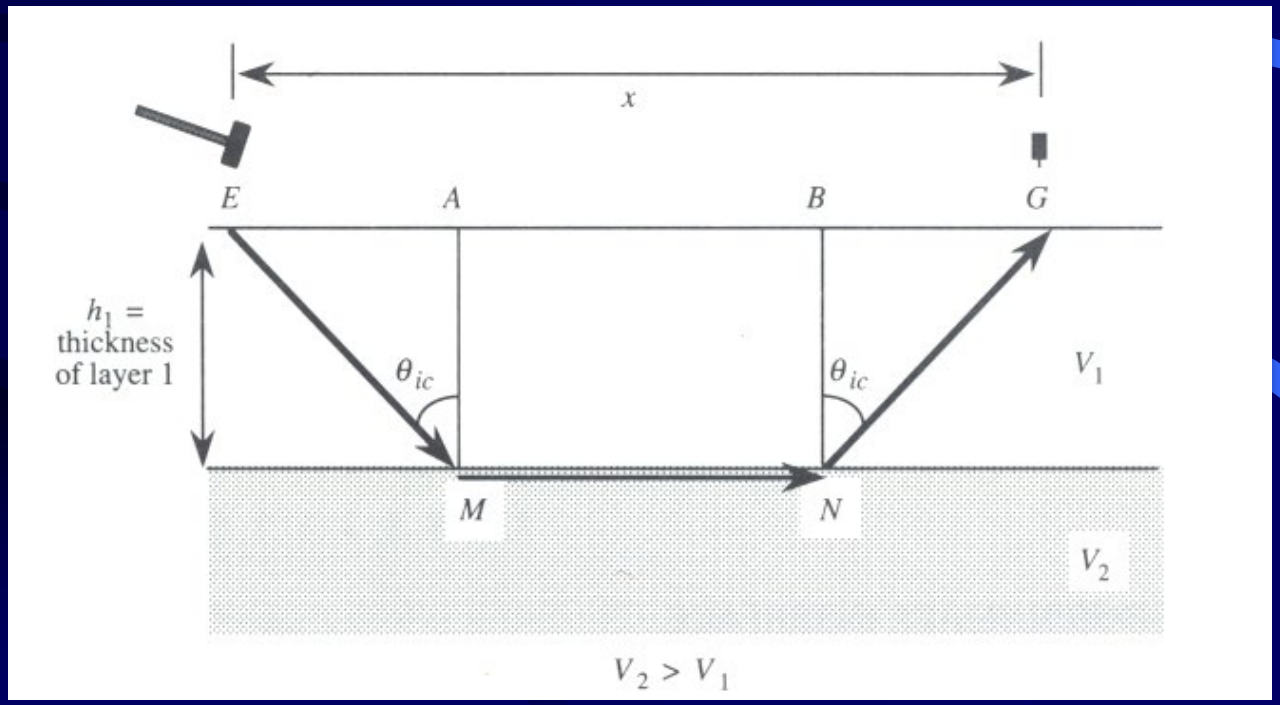
- Equipment for Data Collection

Reflected Wave Raypath



Burger, H.R., 1992. *Exploration geophysics of the shallow subsurface.* Prentice Hall P T R, Inc. p. 136, Figure 4-1.

Refracted Wave Raypath



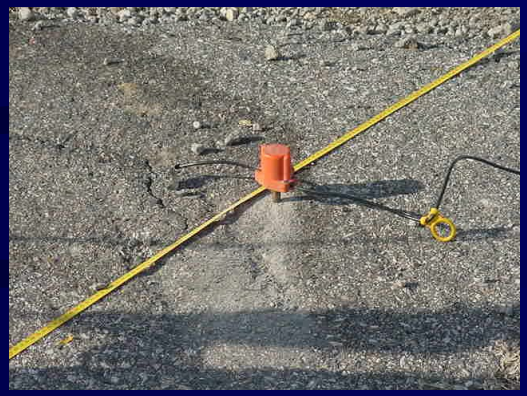
Burger, H.R., 1992. *Exploration geophysics of the shallow subsurface.* Prentice Hall P T R, Inc. p. 60, Figure 3-3.

Seismic Mapping

Stratigraphic Mapping

Reflection or Refraction of Induced Seismic Waves

Equipment for Data Collection



- Strataview R48 Seismograph
- 96 Channel Manual Switch Box
- 48 Channel Reflection Array Cables
- 96 Geophone Receivers
- High Frequency Accelerated Weight Drop
- Static Survey Equipment
- GPS Survey Equipment

Case Study

Physical Site Setting

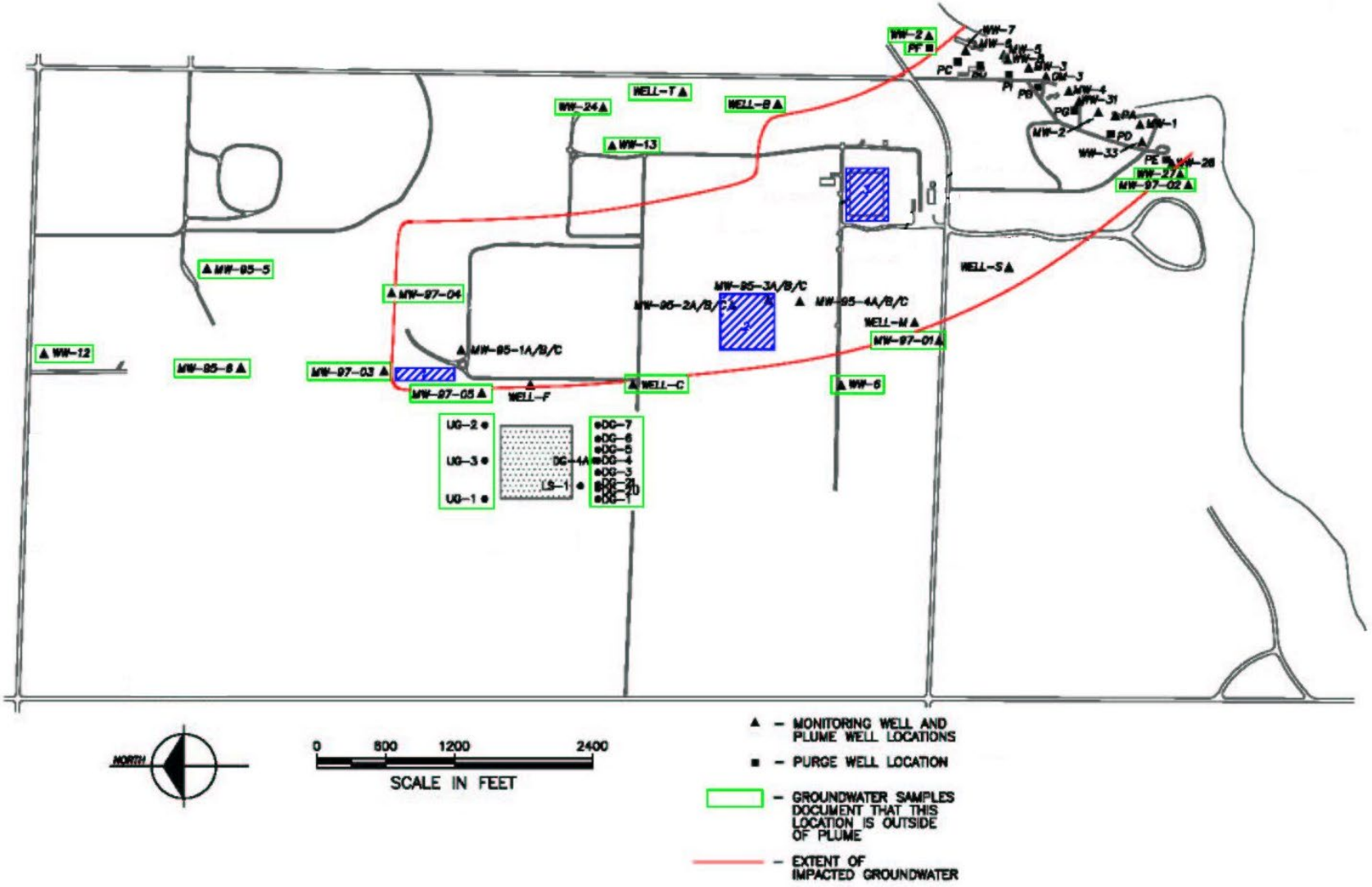
- Former Chemical Production Facility
- Large Site (300+ acres)
- Known Potential Source Areas
- Existing Soil Borings and Wells

Conceptual Geologic Model

- Stratigraphy: Homogeneous Medium
  - Sand Lenticular Clay/Silt Lenses

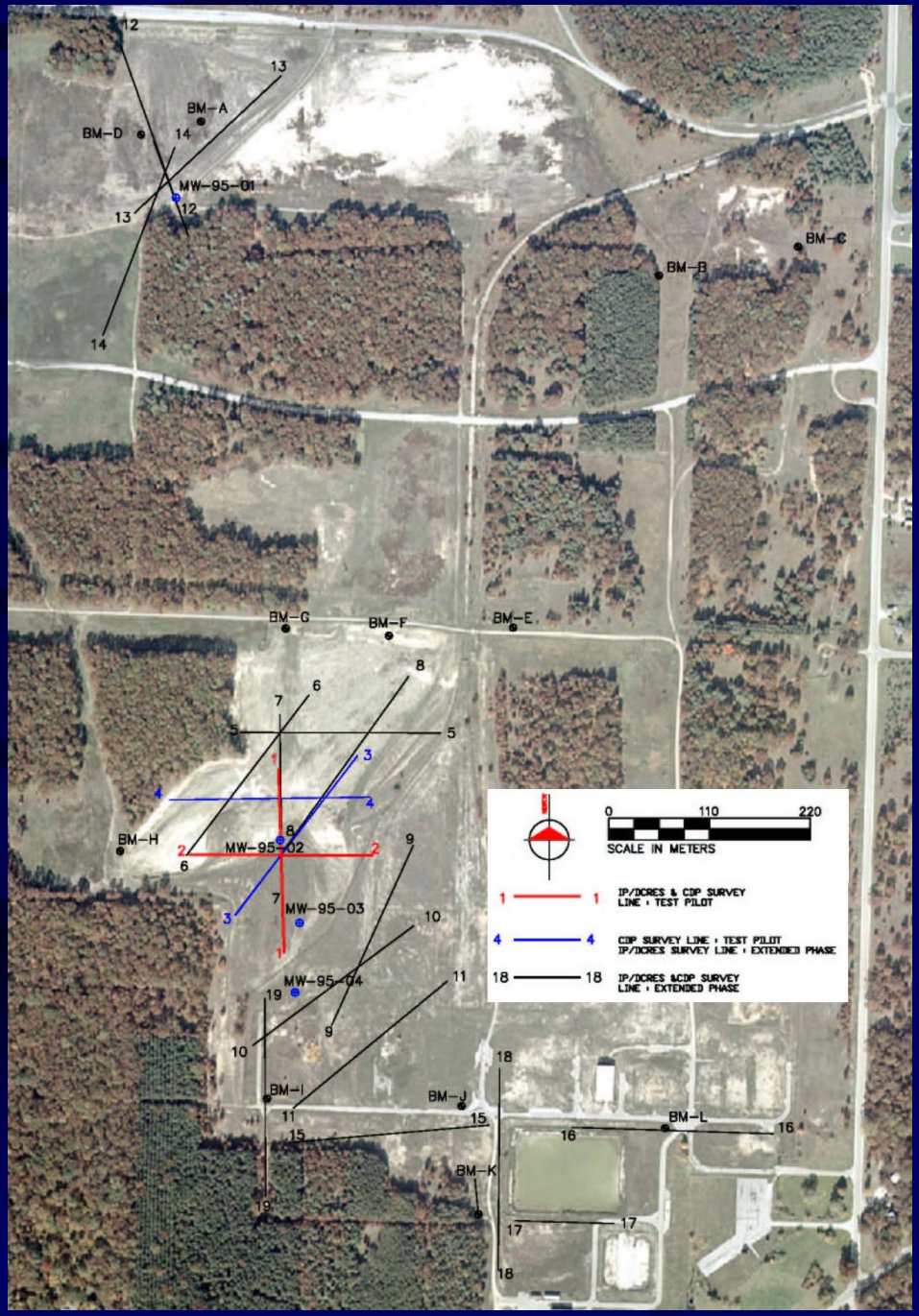
COCs

- PCE, Carbon Tet., PCBs, etc…


MW-2
PF
PC
PI
PD
PE
PG
MW-7
MW-6
MW-5
MW-3
GM-3
MW-4
MW-31
MW-1
MW-33
MW-28
MW-27
MW-97-02
WELL-T
WELL-S
MW-24
MW-13
MW-95-5
MW-97-04
MW-95-3A/B/C
MW-95-2A/B/C
MW-95-4A/B/C
WELL-M
MW-97-01
MW-12
MW-95-6
MW-97-03
MW-95-1A/B/C
MW-97-05
WELL-F
WELL-C
MW-8
UG-2
UG-3
UG-1
DG-4A
LS-1
DG-7
DG-6
DG-5
DG-4
DG-3
DG-2
DG-1
NORTH
0
800
1200
2400
SCALE IN FEET
▲ – MONITORING WELL AND PLUME WELL LOCATIONS
■ – PURGE WELL LOCATION
– GROUNDWATER SAMPLES DOCUMENT THAT THIS LOCATION IS OUTSIDE OF PLUME
– EXTENT OF IMPACTED GROUNDWATER

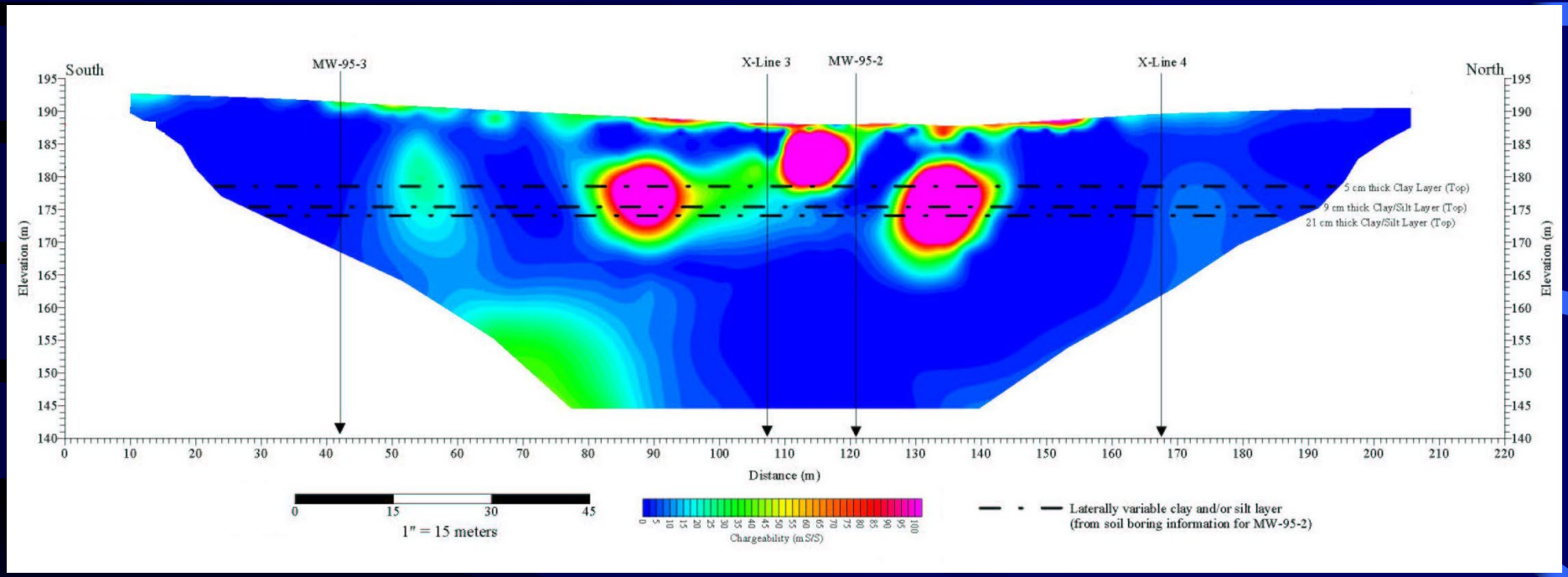
Geophysical Investigation

- Selection of Techniques
  - Pilot Test
- Design of Geophysical Survey
  - Source Areas
  - Survey Line Placement
- Data Collection


BM-A
BM-B
BM-C
BM-D
BM-E
BM-F
BM-G
BM-H
BM-I
BM-J
BM-K
BM-L
MW-95-01
MW-95-02
MW-95-03
MW-95-04
0
110
220
SCALE IN METERS
IP/DCRES & CDP SURVEY
LINE : TEST PILOT
CDP SURVEY LINE : TEST PILOT
IP/DCRES SURVEY LINE : EXTENDED PHASE
IP/DCRES &CDP SURVEY
LINE : EXTENDED PHASE

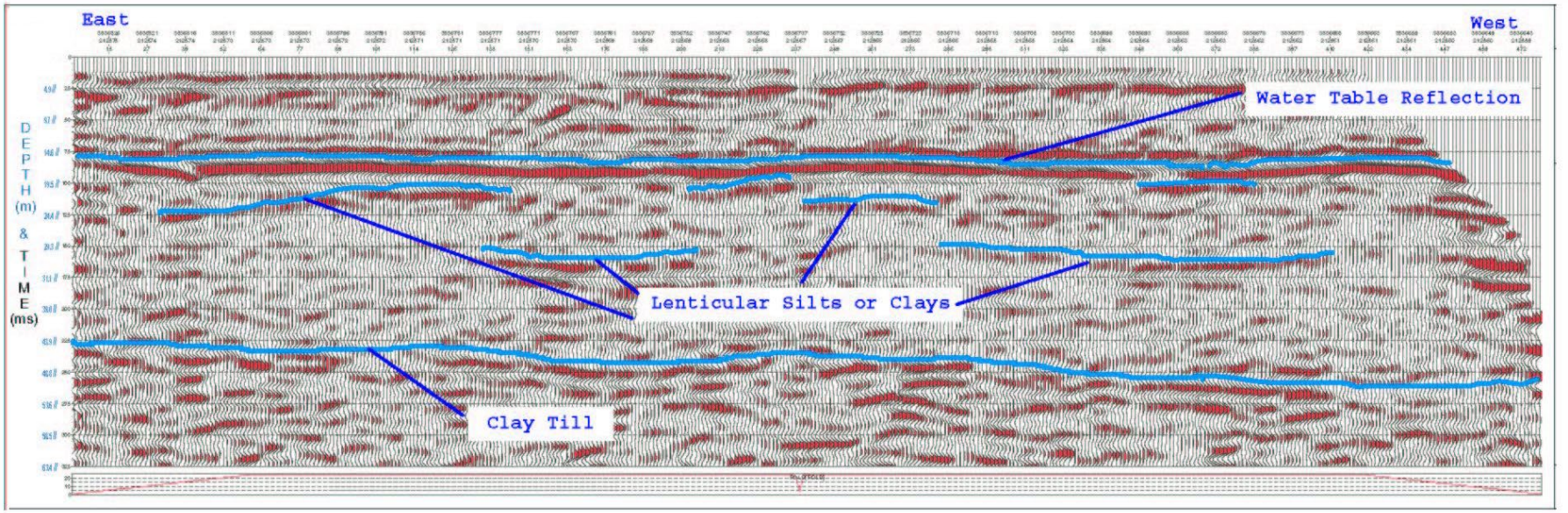
IP Data Processing and Interpretation

- Induced Polarization Data
  - Intensive Computer Processing
  - Figure Generation and Interpretation
- Finding
  - Areas of Elevated Chargeability


South
MW-95-3
X-Line 3
MW-95-2
X-Line 4
North
Elevation (m)
Distance (m)
5 cm thick Clay Layer (Top)
9 cm thick Clay/Silt Layer (Top)
21 cm thick Clay/Silt Layer (Top)
0 15 30 45
1" = 15 meters
Chargeability (mS/S)
Laterally variable clay and/or silt layer
(from soil boring information for MW-95-2)

Seismic Data Processing and Interpretation

- Seismic Reflection Data
  - Processing
  - Figure Generation and Interpretation
- Findings
  - Complex setting for DNAPL migration


East
West
DEPTH (m) & TIME (ms)
Water Table Reflection
Lenticular Silts or Clays
Clay Till

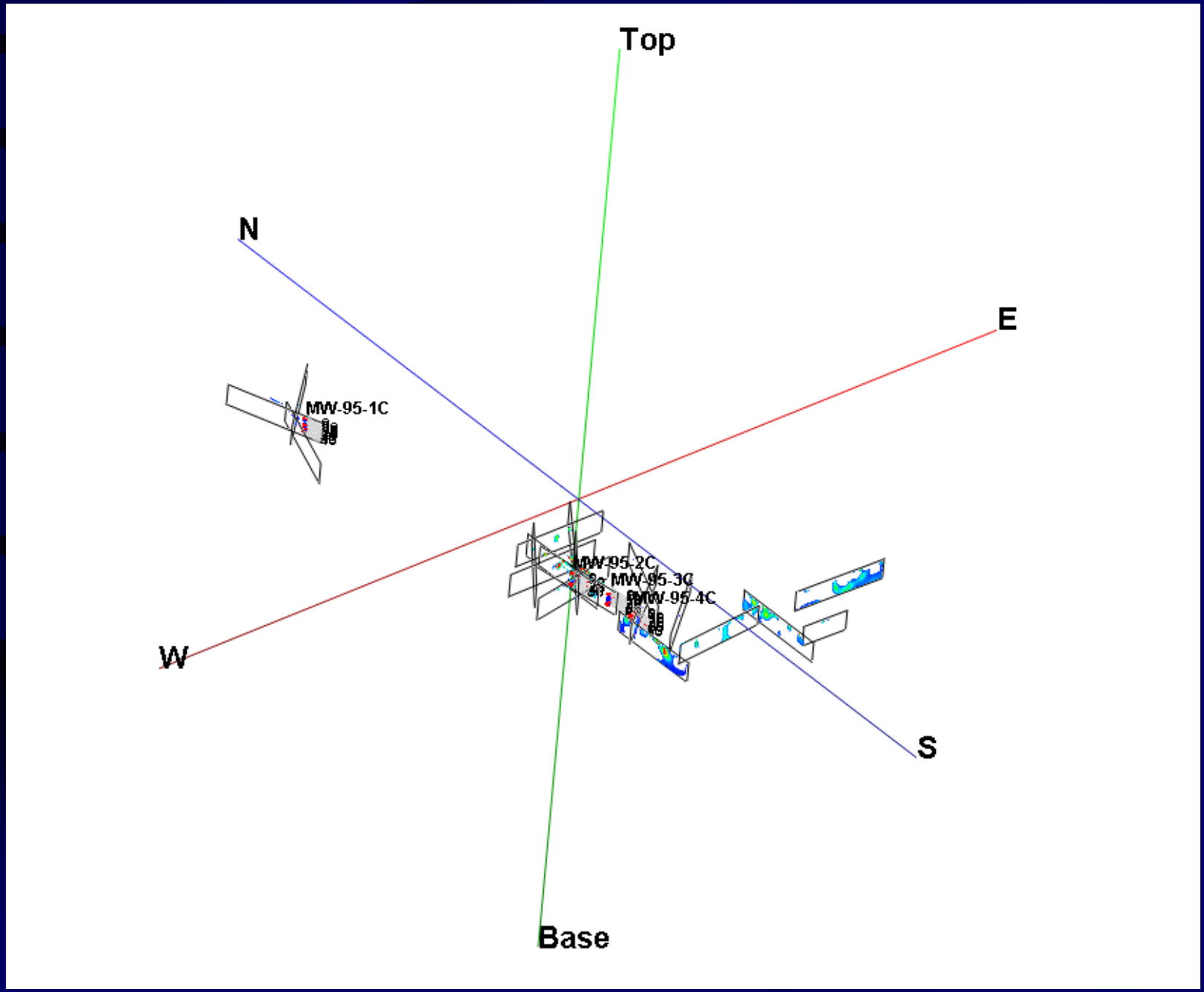
Result: 3D Model of Site

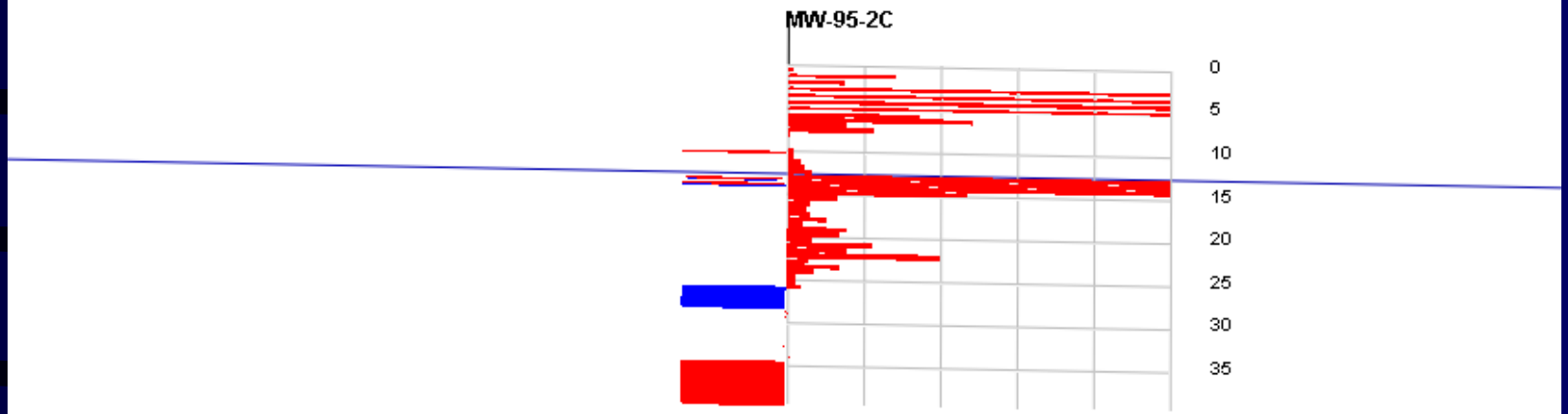
With:

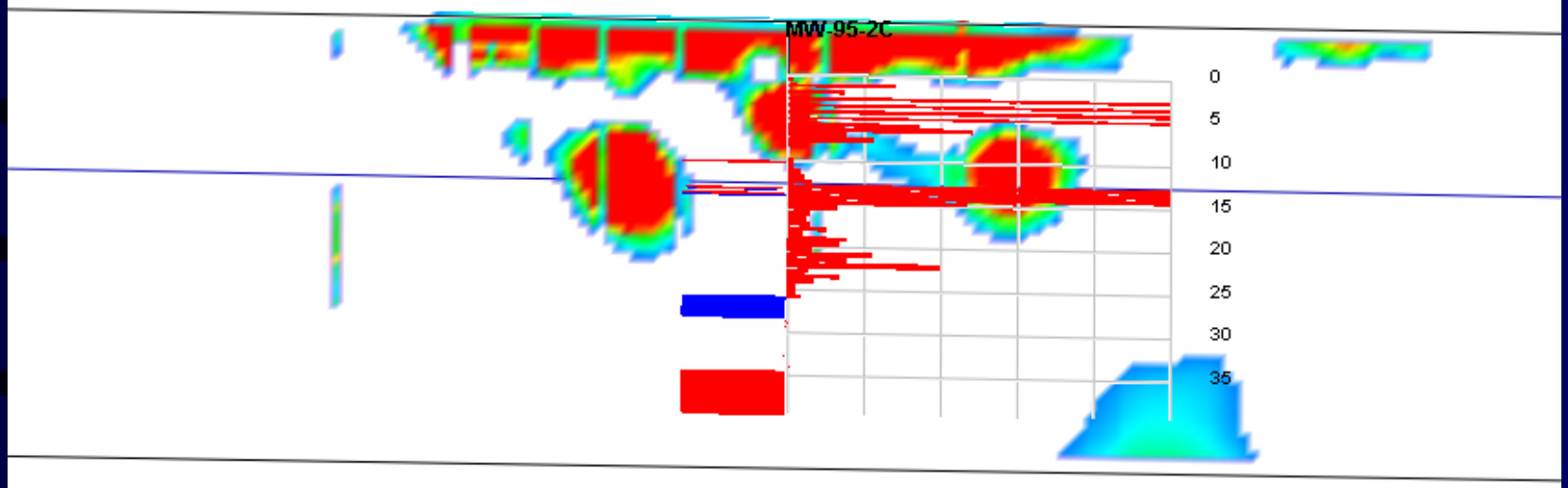
- Definition within known areas
- Identification of new areas

Followed By:

- Confirmation sampling within new areas


Top
N
E
W
S
Base
MW-95-1C
MW-95-2C
MW-95-3C
MW-95-4C


MW-95-2C
0
5
10
15
20
25
30
35


MW-95-2C
0
5
10
15
20
25
30
35

Result: 3D Model of Site

With:

- Definition within known areas
- Identification of new areas

Followed By:

- Confirmation sampling within new areas

Confirmation Investigation

Cone Penetrometer/Geoprobe

- Confirmation of Stratigraphy
- Membrane Interface Probe
- PID, FID, DELCD

Soil Sampling

Well Installation

Groundwater Sampling

DNAPLs Detected in IP Anomalies

Tetrachloroethylene (PCE)

Carbon Tetrachloride

Many Other Dense-Chlorinated Solvents

Conclusions

DNAPL:

- Complex Fate and Transport
- Costly to Locate
- Costly to Remediate

Geophysics will:

- Minimize Investigation Costs
- Maximize Information Return
- Improve remedy selection process

Other Potential Applications

Locate:

- Trichloroethylene (TCE)
- Polychlorinated biphenyls (PCBs)
- LNAPLs

Earth Tech Geophysical Capabilities

- Induced Polarization
- Direct Current Resistivity
- Seismic Reflection Surveys
- Seismic Refraction Surveys
- Passive Electromagnetic
  - EM-31
  - EM-61
- Gravimetric Surveys
- Magnetometor Surveys
- Vertical Seismic Profiles
- Natural Gamma Logging
- Sonic Logging
- Video Logging
- Spontaneous Potential
- Ground Penetrating Radar
- Aerial Surveys
  - Magnetic, Gamma,
  - Thermal, False Color IR

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Steven Townsend, Grand Rapids
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